Spent Fuel Safety

Session # W20

Regulatory Information Conference
March 13, 2013

Rev 2/14/13

U.S.NRC RIC 2013 March 12–14 25TH ANNUAL REGULATORY INFORMATION CONFERENCE

Important Information

- **Badges and Identification** - Visibly display your name badge during the RIC and do not lend or give your badge to anyone.
- **Cell Phones, PDA's and Electronic Devices** – Set cell phones, PDA's and electronic devices to silent or vibrate before the session begins.
- **Exiting During a Session** – If you need to leave the room during a session, wait for a break between speakers, if possible.
- **Exiting at the End of a Session** – For everyone's safety, conference participants are encouraged to leave the meeting room promptly so that room turns, equipment changes and testing can be performed so the next session can begin on time.

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Important Information

- **Audio Recording of Session** - All sessions will be recorded and recordings of each session will be available on the RIC public website post-conference.
- **Presentation Materials** – Presentations received prior to the conference will be available on the RIC public website prior to the conference. Presentations received during the conference will be available on the RIC public website post-conference.

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Session Goals

- Interactive discussion on spent fuel safety
- List of initial topics
- Topics discussed individually by panel
- Audience participation requested at end of topic discussion
- Note card and direct question/answer opportunity at end of session

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Session Topic Format

- Panel member topic presentations
- Lead panel member for each topic
- Panel members provide short response
- Open discussion opportunity for audience

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Session Panel

- Greg Casto - Panel Chair, NRC Office of Nuclear Reactor Regulation
- Richard Daniel - Session Coordinator /Moderator, NRC Office of Enforcement
- Steve Jones - NRC Office of Nuclear Reactor Regulation
- Earl Easton - NRC Office of Nuclear Material Safety and Safeguards
- Gordon Thompson – Institute for Resource & Security Studies
- Mary Lampert - Pilgrim Watch

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Spent Fuel Safety Topics

- **Spent Fuel Pool Defense in Depth** (Steve Jones)
- **The Case for Expedited Transfer of Spent Fuel to Dry Storage** (Gordon Thompson)
- **Expedited Transfer of Spent Fuel from Pools to Dry Casks: Costs and Timing** (Mary Lampert)
- **Expedited Movement of Spent Fuel into Dry Cask Storage** (Earl Easton)

Spent Fuel Defense in Depth Strategies

Steve Jones
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission

U.S.NRC
RIC 2013 March 12–14
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Spent Fuel Storage Background

- Original plan for low-density storage with off-site shipment for processing
- National policy change prohibited reprocessing
  - Transition to high-density pool storage
  - Development of independent dry storage capability

Spent Fuel Pool Status

- Widespread adoption of dry storage as pool storage limits approached
  - High-density pool storage broadly deployed
  - Pool storage nearing capacity at many sites
  - Fuel transfer to dry storage at rate to maintain full core discharge capacity
- Very low frequency of radioactive release
  - NUREG-1353 (1989) and NUREG-1738 (2001)
  - Largest contributor – rare seismic events many times design-basis
  - Other contributors - cask drops and sustained loss of forced cooling

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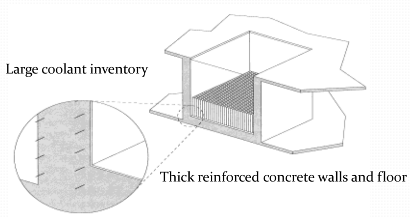
Spent Fuel Pool Structure

- Spent fuel pool designed to prevent loss of coolant
  - Robust reinforced concrete structure with liner
  - Penetrations configured to limit potential for drainage



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Spent Fuel Pool Defense-in-Depth

- Passive strategies to enhance air cooling
  - Maximize air flow through existing high density racks
  - Distribute fuel to avoid hot spots
- Strategies to maintain or restore cooling
  - High capacity makeup water supplies
  - Spray capability to mitigate large leaks

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Response to 2011 Events in Japan

- Validation of design margin for external events
  - Seismic events dominant effect on spent fuel pools
  - Large existing seismic margins
- Mitigation enhancements mandated by orders
  - Reliable spent fuel pool level instrumentation
  - Enhanced spent fuel pool makeup and spray
- Detailed re-assessment of fuel storage density underway
  - Confirm very low frequency of challenges to pools
  - Assess change in various consequence measures resulting from reduced storage density
  - Consideration of alternative regulatory framework

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NRC Annual Regulatory Information Conference, Rockville, Maryland, USA, 12-14 March 2013

Technical Session on Spent Fuel Safety

"The Case for Expedited Transfer of Spent Fuel to Dry Storage"

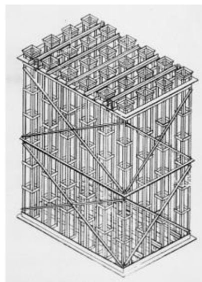
A presentation by Gordon Thompson, Institute for Resource & Security Studies and Clark University, <gthompson@irss-usa.org>

Introduction

- This presentation reflects my professional opinion, and is not on behalf of any other party
- I focus here on the case for expedited reduction of the density of storage in spent-fuel pools – which implies expedited transfer of spent fuel to dry storage
- This focus does not imply that other issues are unimportant
- I can provide documents to back up statements made here

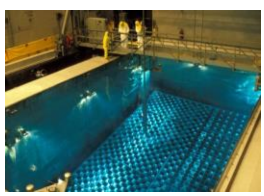
Low-Density, Open-Frame Rack for Storing Spent Fuel (PWR)

• Criticality is suppressed by geometry
• If water is lost, fuel will be cooled by 3-D convective circulation of air and steam
• Spent fuel is passively protected against zirc. self-ignition across a broad range of water-loss scenarios



Storage of Spent Fuel in High-Density Racks

• Criticality is suppressed by cell walls
• If water is lost, heat transfer from fuel will be comparatively feeble, esp. if residual water is present
• Spent fuel will experience zirc. self-ignition across a broad range of water-loss scenarios



Potential for a "Fire" in a Spent-Fuel Pool: Development of Technical Understanding

- This potential was identified in 1978-1979 during expert review of the proposed Gorleben project in Germany
- The regulator ruled in May 1979 that high-density pool storage of spent fuel would not be acceptable at Gorleben; that ruling was applied elsewhere in Germany
- A 1979 Sandia report (NUREG/CR-0649) independently identified the potential for a pool fire
- NRC misinterpreted the Sandia report until 2000
- NRC analytic & empirical work on pool fire has deficiencies, but there is consensus that water loss could lead to a fire and substantial atmospheric release

Risk Implications of Using High-Density Racks in a Pool Adjacent to a Reactor

- The reactor risk is compounded by introducing a new, coupled risk
- The pool often contains short-cooled fuel, which increases fire hazard (e.g., fuel exposed 100 days after discharge could heat up to the point of zirc. self-ignition in about 4 hr; ignition would then spread to older fuel)
- Following reactor core melt, radiation fields etc. could preclude personnel access needed to prevent a pool fire
- At some plants, water from pool leakage or overflow could threaten reactor safety systems

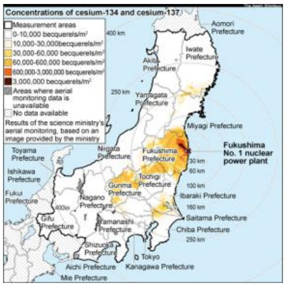
A Wake-Up Call: Fukushima #1 Unit 4

Amounts of Cs-137, Chernobyl & Fukushima

Chernobyl release to atmosphere	85 PBq
Fukushima #1 release to atmosphere	36 PBq (6.4 PBq deposited on Japan)
In Fukushima #1 Units 1-3 reactor cores	940 PBq (total for 3 cores)
In Fukushima #1 Units 1-4 spent-fuel pools	2,200 PBq (total for 4 pools)

Source: Stohl et al, 2011

Deposition of Radioactive Cesium Released During Fukushima Accident



Source: Asahi Shimbun, November 2011

Pool-Fire Risk: Probability

- PRA findings (e.g., CDF = 10^{-5} per RY) don't match cumulative experience (5 core melts in 15,000 RY = 3.3×10^{-4} per RY)
- PRA cannot account for underlying factors such as: complacency and weak regulation in USA (TMI); secrecy in USSR (Chernobyl); industry-government collusion in Japan (Fukushima)
- PRA does not account for potential attack, but:
  - Attackers have means, motives, & opportunities
  - Present defenses address a limited range of threats
  - Plants were not designed to resist attack
  - A high-density pool adjacent to an operating reactor is a beacon of opportunity for attackers

Pool-Fire Risk: Consequences

- Atmospheric release of Cs-137 from a pool fire could substantially exceed 1,000 PBq
- One study (Beyea et al, 2004) estimated a typical, direct economic impact of about $400 billion for a Cs-137 release of 1,300 PBq
- Pool release could be accompanied by reactor release
- Indirect economic impact of a large release could exceed direct impact
- Socio-political impact of a large release could be severe
- A large radioactive release in the USA could lead to phase-out of the nuclear industry

Conclusions

- NRC's traditional cost-benefit analysis calls for expedited reduction of the density of storage in spent-fuel pools – if realistic numbers are used for pool-fire probability and consequences
- NRC's defense-in-depth philosophy also calls for expedited reduction of pool density – this case is similar to the staff recommendation of filtered venting for BWR plants with Mark I & II containments
- High-density pool storage is bad engineering practice, inconsistent with 21st century technology

NRC Annual Regulatory Information Conference
Rockville, Maryland, USA
12-14 March 2013

Technical Session on Spent Fuel Safety

"Expedited Transfer of Spent Fuel from Pools to Dry Casks: Costs and Timing"

A presentation by Mary Lampert
Pilgrim Watch

Is Expedited Transfer More Expensive?

- All spent fuel generated for the foreseeable future will eventually be transferred to dry casks, located at reactor sites or centralized sites
- The cost of transfer to dry casks must be paid sometime. The only question is: When?
- The total number of casks and the size of related facilities will be the same, whether or not transfer is expedited
- Some transfer will necessarily occur before plant decommissioning, as pools become full
- Costs associated with dry-storage may rise in the future
- Expediting transfer should not involve significant additional real cost

Some Potential Sources of Funding

- **Decommissioning Trust Fund**:
  - Monies from fund can be used before decommissioning: 10 CFR 50.82(a)(8)(i)(a)
  - Why shouldn't they be used to expedite transfer?
- **Nuclear Waste Policy Act Funds**:
  - Amend NWPA to allow use of funds now restricted to creating a permanent repository
- **Licensees**:
  - Expedited transfer in response to NRC Order
  - Consider an additional user fee per nuclear kWh
  - Use of decommissioning or NWPA funds could reduce impact on operating expenses

Timing of Expedited Transfer

- The key objective is to reduce risk by re-equipping pools with low-density, open-frame racks
- The transfer plan must expedite rack replacement as well as fuel transfer
- Fuel cooled less than about 5 years can remain in the pools
- Dry casks and low-density racks are proven, licensed technologies
- The USA fought World War II in less than 4 years
- Why can't the nuclear industry significantly reduce risk by moving spent fuel aged more than 5 years out of the pools in a similar period?

Overview

- NRC has determined that spent fuel storage in pools and dry casks are safe
- In light of Fukushima, NRC is reviewing whether the expedited movement of spent fuel into dry casks is warranted
- This presentation discusses some of the factors in the back end of the fuel cycle that are informing this review as well as the challenges to expedited transfer

Expedited Movement of Spent Fuel into Dry Storage

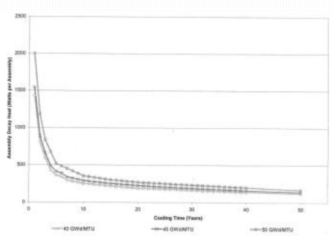


Figure 2-3
BWR SNF Assembly Decay Heat as a Function of Burnup and Cooling Time [NRC 1999, DOE 1992]

Pool inventory reduced by ~ 70%

Decay heat reduced by ~ 30%

Radioactivity reduced by ~ 45%

Potential Impacts of Expedited Movement of Spent Fuel

- Nuclear Power Plants
- Power Plant Workers
- NRC
- Transportation/Storage Package Vendors
- DOE/ “Fedcorp”
- Public

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EPRI Estimates of Dry Cask Loadings needed to move Spent Fuel into Dry Storage after 5 years

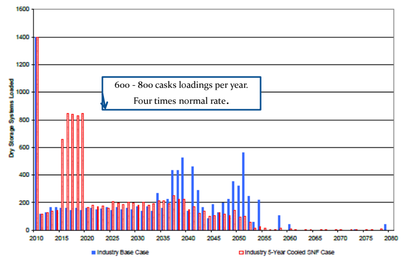

Figure 4-1
Comparison of Dry Storage Systems Loaded Annually Under the Industry Base Case and the Industry 5-Year Cooled SNF Case

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EPRI Estimates of Total Dry Cask Loadings resulting from moving Spent Fuel into Dry Storage after 5 years

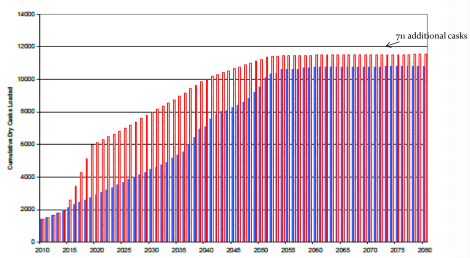

Figure 4-2
Cumulative Dry Storage Systems Loaded Under the Industry Base Case and the Industry 5-Year Cooled SNF Case

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Nuclear Power Plants

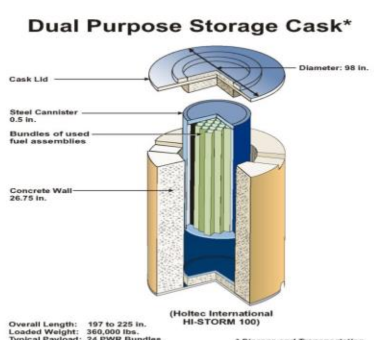
- Larger number of casks needed
- Increased dose for loading operations
- Impacts on schedule – Storage occurs during outages
- Greater cost

NRC and Industry

- Potential need to certify new storage cask designs or amend existing ones
- Ability to inspect cask fabrications or observe cask loadings
- Can industry build quality storage casks fast enough to support a five year campaign?

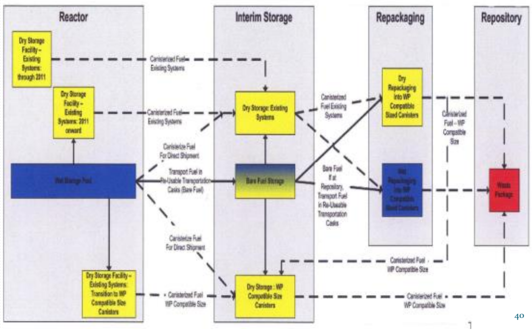
Impacts on the Back End of the Fuel Cycle

- Back end includes storage at reactors, interim off-site storage, and disposal.
- DOE/Fedcorp will be major player
- How casks are loaded for storage at reactors may have large impact on DOE/Fedcorp operations.
- DOE has proposed general interim storage by 2025 and disposal by 2048.



Back End of Fuel Cycle

Source: *System Architecture Evaluation* a presentation to NWTRB by Argonne National Laboratory on 17 October 2012



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Back End of Fuel Cycle

Using Existing NRC-Certified Storage Casks

Dry Storage at Reactors → Interim Storage → Repackaging for Disposal → Disposal

Using Standardized Canisters

Dry Storage at Reactors → Interim Storage → Disposal

Shipping Spent Fuel directly from Wet Storage

Wet Storage at Reactors → Wet or Dry Interim Storage → Packaging for Disposal → Disposal

Impact of Storage Casks

- Using Existing NRC-Certified Storage Casks
  - All canisters may have to be opened, contents repackaged, and canisters disposed of.
- Using Standardized Canisters
  - No repackaging necessary
  - No specification currently exists
- Shipping Spent Fuel Directly from Wet Storage
  - Eliminates the need for storage overpacks at reactors
  - Allows DOE to use reusable transportation casks
  - Allows DOE to use wet storage as an option

Potential Impact on Public

- Storage options may effect:
  - the length of time that spent fuel is stored on site.
  - on-site storage times will probably be determined by the design and throughputs of DOE interim storage and possible repackaging facilities.
  - the number and type of casks that may have to be transported by rail and public highway.

Conclusions

- Safety will come first
- NRC will weigh all factors when determining if regulatory action is needed.
- These include potential impacts on the back end of the fuel cycle.

Open Discussion

- Name and organization
- Question or statement related to spent fuel safety (please stay within the session topic)
- Specific to panel member or any/all
- Panel response

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Closing Statements

- Panel members
- Coordinator/Moderator
- Thank you to panel members and attendees for your time and participation.